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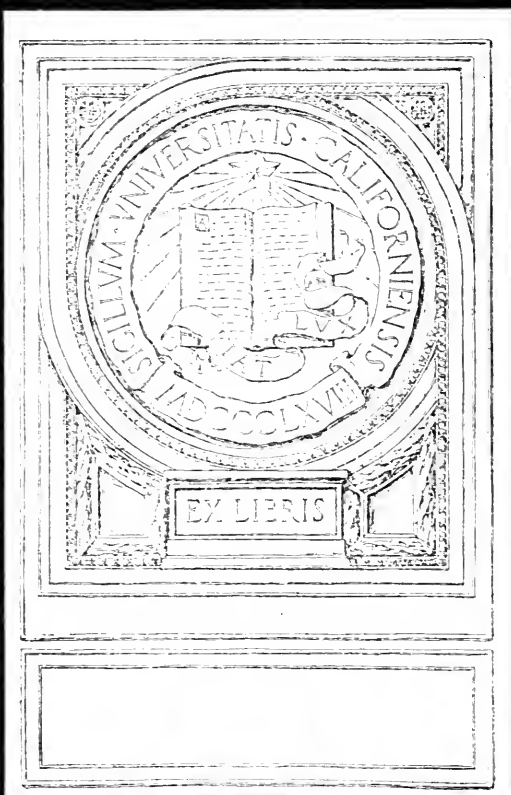
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INFLUENCE OF CERTAIN SOIL FACTORS ON THE GROWTH OF TREE SEEDLINGS AND WHEAT

Barrington Moore

[Reprinted from Ecology, Vol. III, No. 1, January, 1922.]

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BARRINGTON MOORE

CONTENTS

Climate and Soils

The influence of climate upon plants and animals under natural conditions has received more attention than the influence of soil. Climate exerts the major control; without heat, moisture, and light the most fertile soil is useless. In the mountains of our West climate is so closely related to altitude that different climatic zones occur within short distances and give the impression that climate alone influences distribution. In general—of course there are exceptions—those who have studied the environment of western American plants and animals have devoted most attention to climate, while those who have studied in the eastern United States and Europe have considered the influence of geological formation and soil as well as of climate.

Progress in studies of the relation of soil to natural vegetation has been slow, partly owing to the complexity of the problem, and partly because of insistence on the control exerted by physical properties of the soil to the exclusion of its other properties. But there are signs of change. Fernald's work (2) on the distribution of *Pinus Banksiana* and *Thuja occidentalis* has done much to emphasize the importance of geological formation. Hesselman's (4) investigations in Swedish forests have thrown much light on the importance of nitrogen in forest humus and on the influence of various kinds of humus and methods of treatment upon the composition and reproduction of the forest. His discoveries are of the utmost value and will stimulate work on soil factors.

[1] Presented before the Ecological Society of America at its meeting in Chicago on December 28, 1920.

Humus has long been recognized as extremely important; in fact, the accumulation of humus in sandy soils has been considered sufficient to enable such soils to support the same kind of forest as that growing on the more fertile soils of the same climatic region. But, prior to Hesselman's work, the value of the humus had been attributed very largely, if not entirely, to its effect upon the water-holding capacity of the soil. It is known to render heavy soils lighter and better aired, and to make sandy soils less subject to rapid percolation and more retentive of moisture. Its influence has been considered almost wholly from the point of view of its effect upon the physical properties of the soil.

Soil reaction, acidity or alkalinity, is known to be of much importance, but most attention has been given to degree of acidity, with comparatively little study of alkalinity except for toxic salts in arid regions. It would be interesting to know the effect of alkalinity upon tree growth and whether certain trees are kept off of moderately alkaline situations by competition—or because they are unable to grow there.

Experiment

An experiment was carried out in the summer of 1919 at Mt. Kisco, about 30 miles north of New York, to determine as far as possible (1) the influence of humus on tree growth, aside from its effect on the moisture-holding capacity of the soil, and (2) the influence alkalinity produced by slaked burnt lime (calcium hydrate).

From the point of view of fire protection alone, the influence of humus upon tree growth is important. Ground fires, such as those which frequently, often intentionally, run through hardwood forests and longleaf pine forests, destroy a certain amount of humus (3).

Lime is considered beneficial, so that any injury from lime should be due chiefly to alkalinity, although this is not absolutely certain, because it is probable that some trees do not thrive on lime soils which are neutral. The major part of the influence should, however, be due to the reaction.

In studying the influence of humus three soils were used, representing two extremes, absence of humus and pure humus, and an intermediate condition, a mixture of sand and humus. The first soil was pure sand, a rather sterile, fine, grey, water-worn, glacial sand, predominantly quartz, taken from about three feet below the surface of a glacial esker. The physical properties may be summed up by stating that the wilting coefficient, on the basis of air-dry weight, was .85 percent.[2] The reaction was neutral.

The pure humus, the opposite extreme of the pure sand, was a dark brown leaf mold not completely decomposed. It was collected from between crevices in a rock at the base of a cliff to insure a minimum of mineral soil. The

[2] The wilting coefficient figures throughout this paper are approximations, but serve to indicate differences in the physical properties of the various soils.

rock itself was a granite, its decomposed particles underlying the humus and forming the only soil in the crevices. Almost none of these particles were included in the humus used. The forest which created the humus was of mixed hardwoods characteristic of moist rocky ravines in southern New York, Connecticut, and Pennsylvania (9). It contained white oak, *Quercus alba,* chestnut oak, *Q. prinus* (on the rockier places), red oak, *Q. rubra,* much sugar maple, *Acer saccharum,* black birch, *Betula lenta,* a little beech, *Fagus Americana,* a little shagbark hickory, *Hicoria ovata,* some white ash, *Fraxinus Americana,* and a scattering of dead chestnut, *Castanea dentata,* which had probably contributed its quota to the leaf mold. The reproduction was fairly abundant of chestnut oak, red oak, sugar maple, and white ash. Among the shrubs of the undergrowth was some laurel, *Kalmia latifolia,* viburnum, and a little dogwood, *Cornus florida.* Higher up the slope and about 50 to 75 yards away was a group of hemlock.

The wilting coefficient of this humus, on the basis of air-dry weight, was 43.5 percent. The acidity, determined by titration of an aqueous extract with .05 normal sodium hydroxide in the manner described by Coville (1) in his blueberry study, was .00114 normal at the start of the experiment, and was reduced by exposure from June 8 to September 12 to .00075 normal. By the Truog test (10), applied before exposure, it was between "medium" and "strong" acidity, nearly "strong"; after exposure this test revealed practically no change. Wherry's colorimetric method of determining the hydrogen and hydroxyl-ion concentration (11) had not been made available at the time these tests were carried out.

The intermediate soil was a mixture of the sand and humus above described in the proportion of 80 percent sand and 20 percent humus by volume. Owing to the lightness of the humus it made only 4 percent by weight and did not give the sand an appearance of a high humus content; in fact, it is probably somewhat lower than the surface layers under a typical forest of pitch pine. The addition of this amount of humus raised the wilting coefficient from .85 percent to 2.4 percent. The acidity became .001 normal before exposure and was of "medium" acidity by the Truog test.

In order to eliminate the effects of greater moisture-holding capacity, and to find the influence of humus on the nutrient properties of the soil, all soils were kept continually moist.

In the alkalinity tests a set of three soils, similar to the three above described except for the addition of lime, was used. The sand received 2 percent of air-slaked burnt lime by volume and the humus received 4 percent. The sand and humus received 2 percent of lime for the sand and 4 percent for the humus. It has been commonly supposed that burnt lime in the soil quickly absorbs carbon dioxide and assumes the neutral carbonate form. In a study of the comparative effects of burnt lime (CaO) and calcium carbonate ($CaCO_3$) on the soil reaction Hoagland and Christie (6)

found that the burnt lime makes the soil strongly alkaline; this decreases greatly in 3 days, and after that more slowly, leaving the soils still alkaline after 10 months.

The alkalinity of these three soils was determined by titration with normal hydrochloric acid in .05 normal solution in the same way that the acidities were tested. The sand was .0058 normal alkaline at the beginning and was reduced to .00117 after 96 days' exposure. The mixture of sand and humus was .0036 normal alkaline at the outset and dropped to .00116 normal, or practically the same as the sand. The humus was very alkaline, .0127 normal at first and decreased to .00283 at the end.

A third series of soils, the same as the foregoing, but with a milder application of lime, was added on June 23, fifteen days after the other two series had been started. In this set the sand received only .75 percent of burnt lime: the mixture of sand and humus received .75 percent for the 80 percent of sand, and 1 percent for the 20 percent of humus. The humus received only .5 percent of lime. Titration tests showed that the sand had an alkalinity of .00127 normal at the beginning, which decreased to .00097 by August 29. The mixture of sand and humus was .00097 normal at the start; and the humus was only .00065 normal alkaline in the beginning and was neutral at the end. The alkalinity in this series was therefore comparatively low.

The addition of the larger amounts of lime appears to have slightly affected the physical properties. The wilting coefficient of the sand was reduced from .85 to .76 percent, and that of the sand and humus from 2.4 to 1.5 percent. The wilting coefficient of the humus was 50.2 percent with the lime, as against 43.5 percent without. With humus the lime caused the formation of a surface crust, due apparently to rapid carrying to the surface of water containing salts in solution, the water evaporating and leaving a crust of salts. This explanation would agree with Wolkoff's (**12**) work on the influence of alkali salts on soil moisture. The crust interfered with germination and re-formed as soon as broken.

The soils were placed in flats of cypress, *Taxodium distichum,* to avoid the influence of decaying wood. These flats were 8 centimeters deep inside, and 48 centimeters long by 37 centimeters wide. Each was filled level with the edge, but the humus settled with exposure more than the sand until it became about 5 centimeters deep as against about 7 for the sand. On June 8 each flat containing a soil as above described (except the light lime series) was sown with seed of red pine, *Pinus resinosa,* Jack pine, *Pinus Banksiana,* pitch pine, *Pinus rigida,* and white cedar, *Thuja occidentalis.* White pine, *Pinus strobus,* was also included, but did not germinate sufficiently to give results worth noting.

On June 10 five sugar maple seedlings one year old, of wild stock collected from the immediate vicinity, were transplanted into each of the six flats.

On June 12 all flats received a row of marquis wheat kindly furnished by H. L. Shantz, of the Bureau of Plant Industry. The mild lime series was sown with the same species on June 23, except wheat, which was put in on June 24.

All flats were protected from birds and rodents by rust-proof wire netting with a 6 to 7 mm. (about quarter inch) mesh, since it had been found in previous work of this character that coniferous seed in unprotected flats is largely destroyed. Perhaps the flats attract curiosity and expose the seed to more danger than in a forest nursery. The wire cut off a certain amount of sunlight, perhaps about 20 percent or more; this was an advantage, since exposure to full sunlight is not beneficial to very young coniferous seedlings.

Measurements of the growth in height were made at about five-day intervals up to August 4, and then on September 12. The measurements were taken from the ground to the base of the cotyledons, and when the primary leaves appeared these were measured and their length added. The growth of the maple was taken by measuring the length of the primary leaves alone.

At the end of the season the growth of the roots for the entire period and the green weight of the seedlings were determined.

Results

The results on the unlimed, strong lime, and mild lime series will be presented separately. The first series shows the influence of humus, and the second and third the influence of alkalinity and of lime in different proportions. The rate of growth is shown in the accompanying curves, figures 1, 2, 5, and 6, and the data on root growth and green weight is presented diagrammatically in figures 3 and 4.

Influence of Humus

Rate of Growth in Height.—The rate of growth in height of each species has been plotted separately, but all three soils in the series are placed for comparison on the same graph. The results of the mild lime series have been included in the humus graphs for pitch pine, jack pine, and red pine, figures 1 and 2.

The differences shown are in no wise due to the effect of humus upon water relations, but upon the nutrient properties of the soil—its fertility. The physical properties of the soil do not enter into the problem except through effect on aeration, and in this series all the soils were porous enough to give abundant oxygen to the roots.

The favorable influence of humus shows strikingly. In spite of acidity there was far more rapid growth of all species on pure humus than on pure sand (see figures 1 and 2). The cause is almost certainly the nitrogen content of the humus and the lack of it in the sand. The nutrient value of

humus and its influence on rate of growth in certain forests seems amply demonstrated.

Surface burning in a forest, by adding ashes to the soil, may stimulate growth temporarily; but, since it destroys the nitrogen which is seen to be such a large factor, and allows the remaining nutrients to be rapidly carried off by rain, its ultimate result must be to seriously check growth.

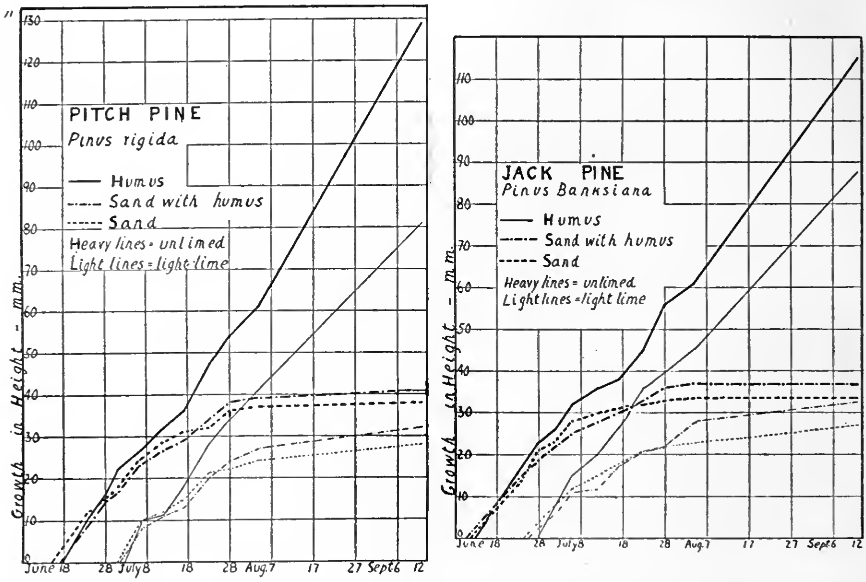

FIG. 1. On left, pitch pine seedlings, rate of growth in height on unlimed (heavier lines) and on lightly limed soils (lighter lines), showing the strong response to humus. On right, Jack pine seedlings, rate of growth in height on unlimed and on lightly limed soils, showing the influence of humus.

On the sand to which 4 percent of humus by weight had been added the growth rate was more rapid than on the pure sand, except in the case of cedar, which will be considered below. The difference in the growth of the trees on the pure sand and on the sand plus humus was not great, but distinct. It is interesting that the improvement produced by the addition of the humus to the sand, so far as trees are concerned, bore a closer relation to the proportion of humus in the sand by weight than by volume. The amount added by weight was small, 4 percent, and the increased growth of the trees was small. This would indicate that in forests the customary practice of measuring the percentage of humus by weight rather than by volume may be the better after all. The growth was, however, only that of a single season, a very short proportion of the life of a tree, and later growth might show the humus mixed with the sand to have a greater influence than that indicated by

these curves. With wheat the influence of the humus added to the sand was greater than with the trees, and was more nearly in proportion to the volume of humus in the soil.

The favorable effect of the humus, either pure or in mixture, was not at once apparent. Germination was more rapid on the sand. If this was due to heat, it must have been on account of the smaller amount of water in the sand even at its optimum moisture content, and possibly to its greater con-

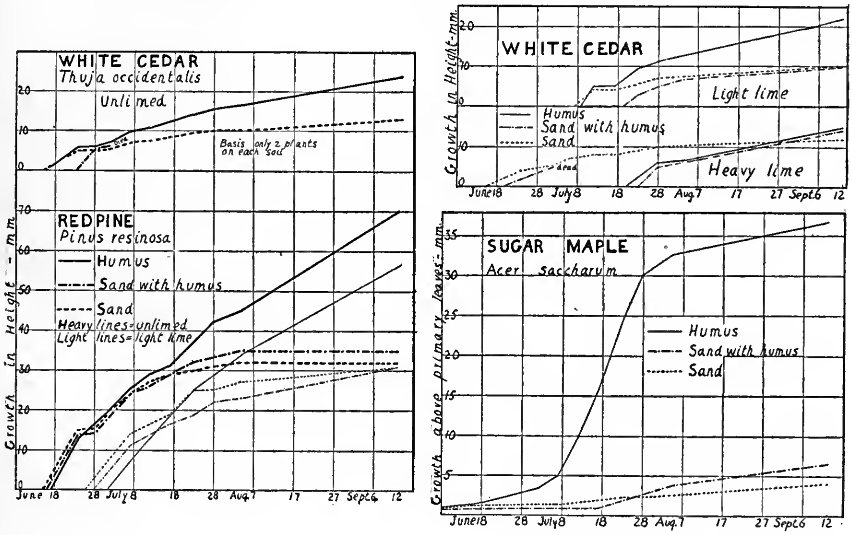

FIG. 2. On left, growth in height of white cedar (arborvitae) seedlings on unlimed soils; and of red pine seedlings on unlimed and on lightly limed soils; showing smaller response to humus on the part of cedar and red pine (compare with fig. 1).

On right, white cedar seedlings on lightly limed and on heavily limed soils. Shows later germination on heavily limed humus, and on sand with humus, but relatively less injury from lime than in the case of other species (compare figs. 1 and 6).

Sugar maple one-year-old transplants on unlimed soils, showing the influence of humus on the rate of growth in height above the primary leaves.

ductivity, for the sand was light colored and absorbed considerably less heat than the darker humus. It may be that the seeds absorbed water more rapidly from sand than from humus, because the humus was not thoroughly decomposed, and hence could not be packed as closely about the seeds as could the sand.

All species did better at first on the sand than on the mixture of sand and humus, but eventually those on the latter caught up with and passed those on the former; this occurred at about the same time for all trees. It may be that the nitrogen in the humus became available after a certain period of exposure.

All species responded, but not equally, to the humus by a very marked increase in rate of growth. The response of Jack pine and pitch pine was considerably greater than that of red pine and cedar (see figs. 1 and 2). Jack pine and pitch pine are largely confined to the poorest and sandiest soils within their ranges. It may be that their strong response to humus is correlated with the character of the soil on which they ordinarily grow, and that they are able to persist on poor sandy soils because of this very ability, for there is always a considerable amount of humus mixed in with the sand of their natural habitat. The response of red pine and cedar to humus would be proportionally less than that of Jack pine and pitch pine, because they need other elements in the soil. It would seem that the greater the response to humus, the poorer the soil on which a coniferous species will thrive. Of course, the matter is not so simple as this, and will require much critical work on the availability of the various components of the soil solution, as well as on the physiological processes of absorption and metabolism, before any such law can be stated.

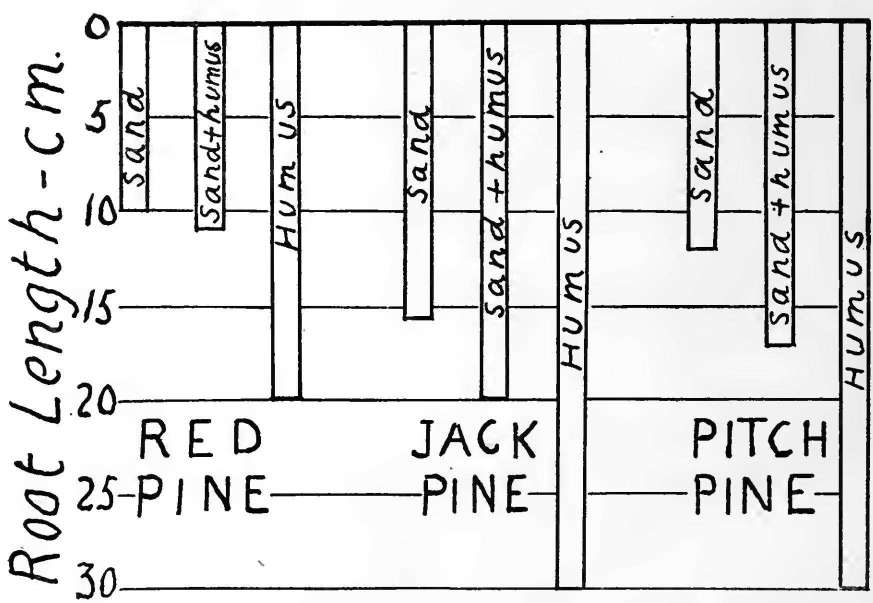

Fig. 3. Growth of coniferous seedling roots in length on unlimed soils, showing the influence of humus. Root area would have shown even greater influence.

Cedar, curiously enough, grew on the pure sand and on the pure humus.

The rate of growth fell off earlier in the season—by about July 8—on sand than on any other soil; on the mixture of sand and humus it diminished a little later, while on the pure humus a high rate was maintained by most species until the last measurement on September 12.

but not on the mixture of sand and humus. The reason is unknown, unless it be that cedar will not tolerate acidity unless the acidity be compensated for by an abundance of humus. Fernald has shown (2) that cedar exhibits a marked preference for calcareous soils; the writer has found much cedar growing on Mt. Desert Island, Maine, where the soil was not calcareous, but contained abundant humus.

Growth of Roots and Green Weight.—The influence of the humus on root growth was as marked as its influence on height growth. The roots were not only longer, but more branched, and therefore had a much larger absorbing area than on the sand. In spite of the shallowness of the flats the roots on the humus attained lengths of from 20 to 30 cm., as against 10 to 13 cm. on the sand, and 11 to 20 cm. on the mixture of sand and humus (Table 1).

The effect on the growth of roots *in length* is shown in Table 1 and represented graphically in figure 3. This gives only part of the influence of humus, because it ignores the branches, and hence does not represent differences in total root area. Had it been practicable to measure the length of all the branches, the influence of humus would have been exhibited even more strikingly.

TABLE 1. *Growth of roots in length, unlimed soils*

Species	Soil		
	Average length, cm.		
	Sand	Sand with 4% humus by weight	Humus
Jack pine	13	20	30
Pitch pine	12	17	30
Red pine	10	11	20

The roots of Jack pine and pitch pine were longer than those of red pine, as would be expected from the drier and poorer soil in the native natural habitat of these species. It is not, however, safe to draw general conclusions as to the relation of depth of root to moisture and fertility requirements, because the response may be due to one of several factors, among which are not only moisture and fertility, but soil oxygen.

The influence of humus on green weight per seedling at the end of the growing season is given in Table 2 and shown graphically in figure 4. Although the difference between the pure sand and pure humus is very marked, the difference between the pure sand and the sand with 4 percent humus by weight, though distinct, is not very noticeable. The greater response which Jack pine and pitch pine make to humus, as compared with red pine, shows in the green weight as in the height growth.

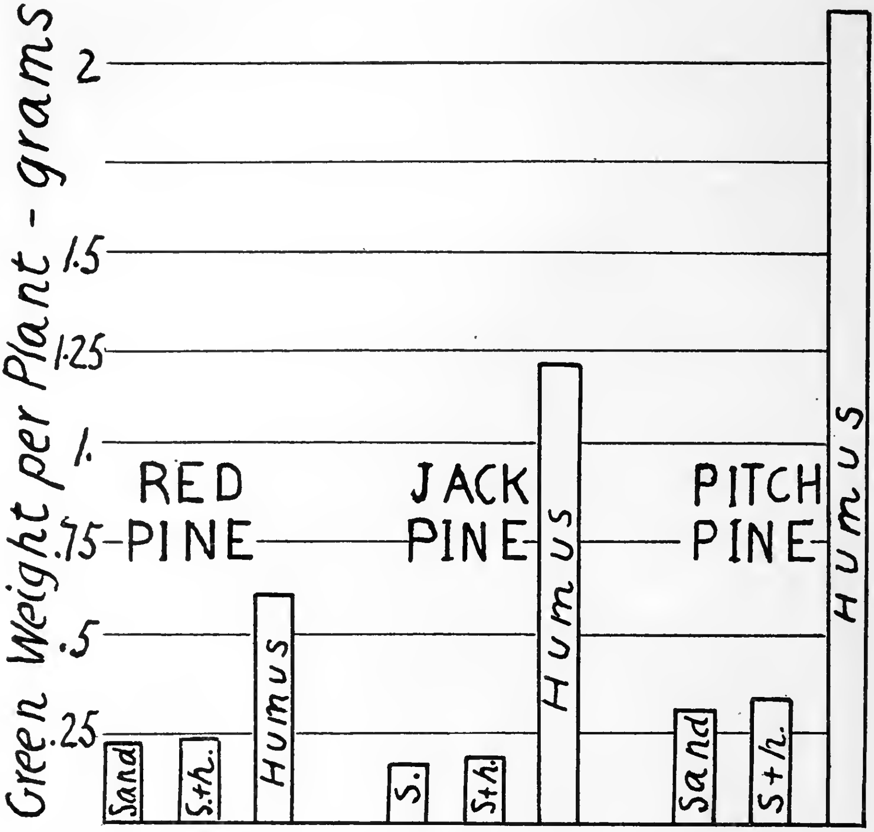

FIG. 4. Green weight of coniferous seedlings on unlimed soils, showing response to humus.

TABLE 2. *Green weight*

Species	Soil		
	Average green weight per plant, grams		
	Sand	Sand with 4% humus by weight	Humus
Jack pine	.167	.18	1.215
Pitch pine	.31	.34	2.14
Red pine	.222	.228	.607

Pitch pine showed the greatest green weight, as well as the tallest height growth, and had a slightly more uniform growth throughout the season (see figs. 1 and 2). This may be because the climate was best suited to pitch pine, for it alone occurs naturally in the vicinity, or it may be merely a specific character.

The effect of humus showed in the color of the plants, those on the mixture being slightly darker than those on the sand, which were a yellowish green, while those on the humus were bluish green, indicating greater thrift and vigor.

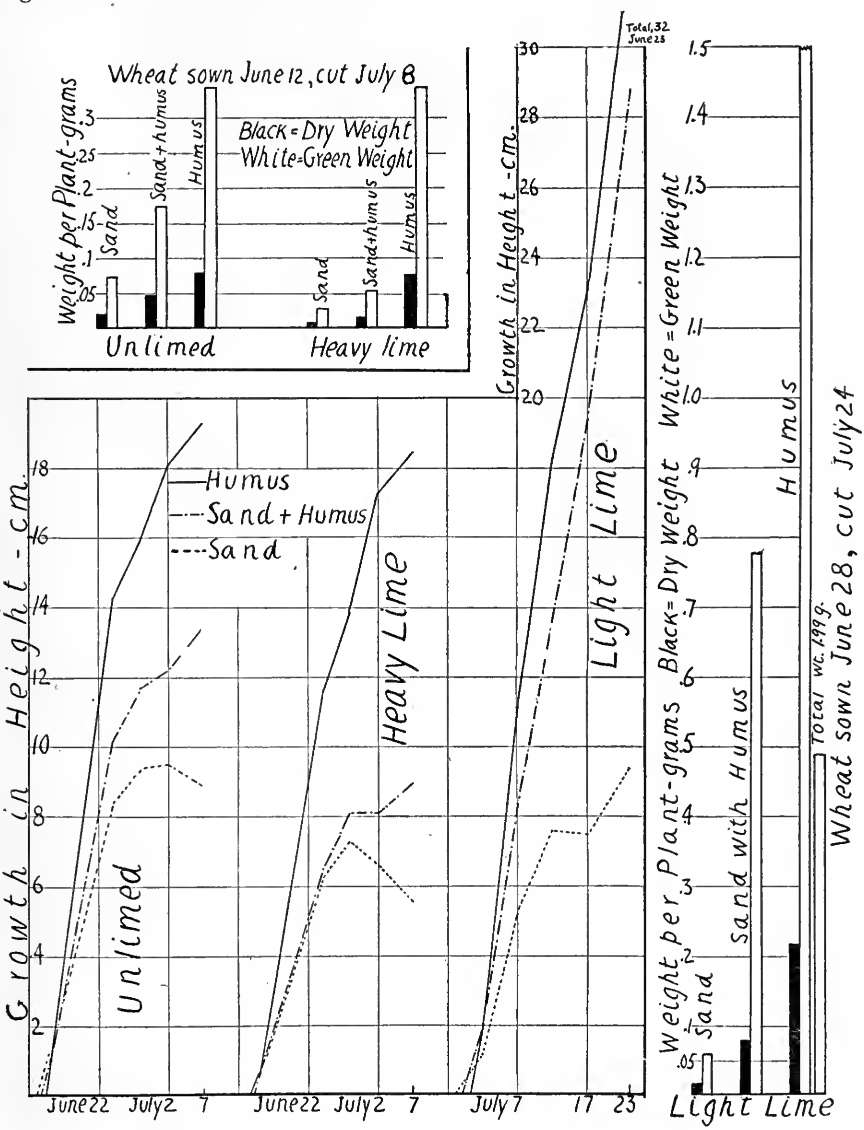

FIG. 5. Wheat, rate of growth in height, and green and dry weights, on the three soils of the three series. Green and dry weights are in upper left hand corner and on extreme right of figure. Shows less injurious effect of heavy lime as compared with coniferous trees (except cedar).

Influence of Humus on Wheat.—The influence of humus on the rate of growth of wheat was very marked, although the proportionate increase on the humus was considerably less than in the case of the trees. Is this a further indication that plants requiring fertile soil respond less readily to humus than those which do well on poorer soil?

The period of growth was only 26 days, further growth on the humus being hampered by the wire screens. This is, however, sufficient with such a rapidly growing plant to show the influence of humus. At the end of the 26 days the plants on the sand were dying back at the tops (see fig. 5). The green and dry weight per plant, exclusive of roots, are given in Table 3.

TABLE 3. *Green and dry weight of wheat tops on unlimed soils*

Soil	Green weight per plant, grams	Dry weight per plant, grams
Sand	.073	.020
Sand with humus	.174	.048
Humus	.343	.0792

The wheat plants on the humus showed the effects of the low carbohydrate and high nitrogen content of the soil by forming several stems to the plant instead of a single stem as with those on the sand. This agrees with the results already obtained by several workers (7 and 8) on the influence of the carbon-nitrogen ratio.

Influence of Alkalinity

Heavy Application of Burnt Lime.—The effect of alkalinity produced by the moderately heavy applications of air-slaked burnt lime was very unfavorable to all species except cedar. It is significant that cedar came up and looked thrifty on the limed mixture of sand and humus, whereas it died back on the unlimed, and that growth on the limed pure sand was practically the same as on unlimed sand instead of much inferior as it was with the other trees. On the limed humus it was prevented from coming up by the crust until a four days' rain from July 18 to 22 permitted the seeds to germinate on the surface, after which they grew well. Thus the alkalinity, though perhaps not favorable to the cedar, was far less unfavorable than to the other trees. The behavior of cedar corroborates Fernald's work on lithological factors (2), in which he brings out the preference of the species for limestone soils.

The unfavorable effect of alkalinity agrees with the work of Hoagland (5), who found that for barley alkalinity is more unfavorable than acidity for the same departure from the neutral point; here we see that alkalinity is harmful to trees as well as to barley. It is even probable that, except for certain trees like cedar, which grow best on lime soils, alkalinity is even more injurious to trees than to most crop plants.

The sugar maple seedlings, being transplanted only two days after the

flats had been set out, received the effects of the higher alkalinities before there had been much decrease. On June 11, the day after transplanting, the sugar maples on the limed soils had dropped their leaves to a vertical position, one on the limed humus had already died, and but one plant had its leaves horizontal, and that was on limed sand. On the unlimed soils the leaves were horizontal except for a few which were at 45 degrees. By June 15 all the maples on the limed soils, except two on the sand, were dead, while all on the

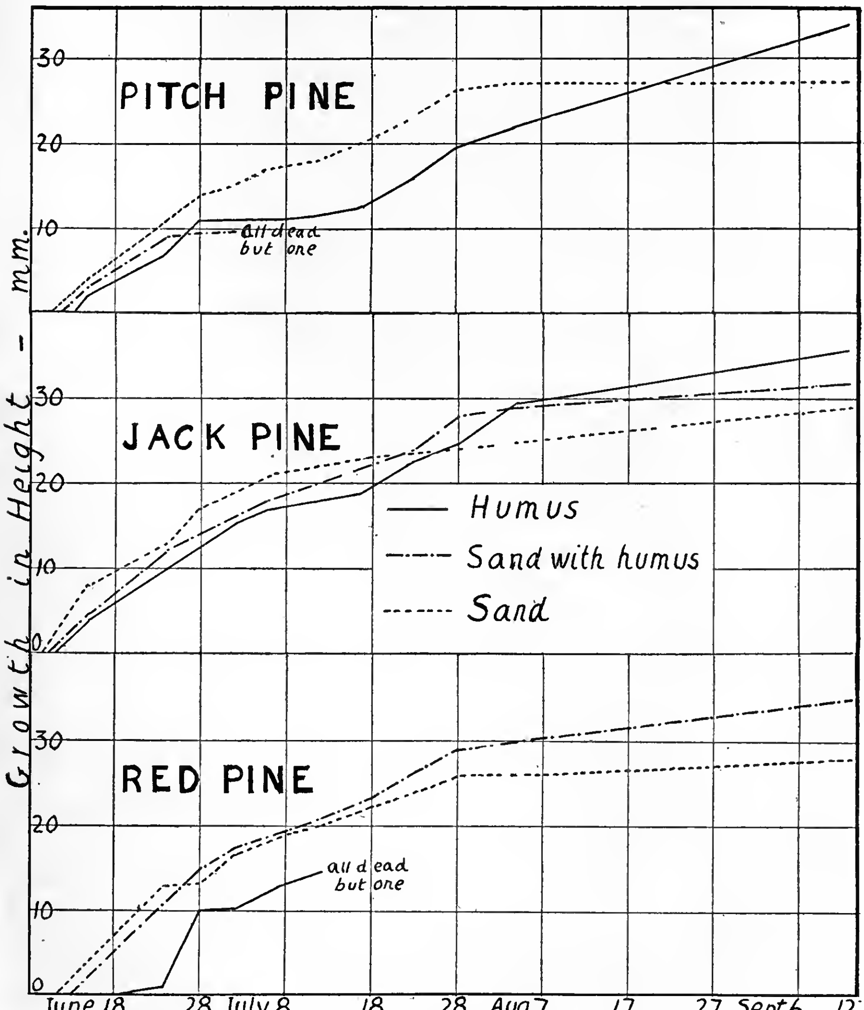

FIG. 6. Rate of growth in height on heavily lined soils, pitch pine, Jack pine and red pine seedlings. Shows the injurious effects of alkalinity, and its nullifying the benefits of the humus. Compare with figures 1 and 2 (remembering that figs. 1 and 2 are reduced about twice as much as fig. 6).

unlimed soils were living and apparently thrifty. The two on the limed sand survived through the season, one with only one leaf, and made a small growth about equal to those on the unlimed sand. The limit of endurance of alkalinity by sugar maple is therefore probably less than .003 normal. The limits of acidity have not been determined, but it has been found growing in Maine in a humus with a hydrogen-ion concentration, determined by the Wherry method (11), of P_H 4.5, or specific acidity of 300.

The toxicity of the burnt lime showed almost as soon as germination occurred. On the humus, probably on account of the surface crust, seedlings came up on only about a quarter of the rows, except pitch pine, which came up on about two thirds. On the sand and mixture of sand and humus germination was about the same as on the unlimed soils. But soon after germination a striking difference between limed and unlimed was apparent. By June 24 half of the Jack pine and a third of the pitch pine on the sand were unhealthy and shortly afterwards died; four fifths of the pitch pine and more than half of the Jack pine and red pine on the mixture of sand and humus were sickly and soon died. On the humus the Jack pine was in poor condition, the pitch pine had many unhealthy, and of the red pine only a small number were up.

From the point of view of survival the sand had the least ill effects of the three limed soils, and the mixture of sand and humus the most, though the humus was nearly as bad. By the middle of the season the flat containing limed sand and humus was almost bare, and the humus flat not much better. One red pine was living on the humus by July 12, and on the sand and humus all the pitch pine were dead by July 2. Records of the rate of growth on the limed soils are consequently based on a much smaller number of plants than those for unlimed soils.

Toxicity of burnt lime, though marked throughout the season, seems to have diminished somewhat in intensity by about July 17, or about 40 days after the exposure of the soil to the weather.

It is curious that the lime seemed to nullify to a considerable extent the beneficial influence of the humus. This may be due, in part at least, to the heavier application of lime received by the humus as compared with that given the other soils of the series.

The tops of a few individual plants showed the effect of the lime by becoming nearly white, not yellowish white. The stems, particularly on the sand and mixture of sand and humus, were short and crooked, and often the plants were lying prone against the soil, though alive and growing.

Root growth was very markedly affected by the lime. Back of the normal colored growing tip the root became brown and shriveled, sometimes for its entire length; often it would be unnaturally twisted, and in many cases the upper part came out of the ground and lay on the surface, the stem of the

plant turning upward. The length of the roots on September 13 is given in Table 4.

TABLE 4. *Root growth on heavily limed soils*

Species	Soil		
	Average length of roots, cm.		
	Sand	Sand with humus	Humus
Jack pine	8	8	12.5
Pitch pine	7	...	10
Red pine	9	7	....
White cedar	5.4	2.5	5.2*

* Younger than on other soils.

In one case the roots of 6 Jack pines growing on the limed sand had joined and, for a length of 4 millimeters from the end, were closely intertwined as though forming a single root-tip. The intertwined tips appeared healthy, the rest of the roots brown and shriveled, with perhaps 10 millimeters above ground. The seedlings were all living. Is this an example of mutual benefit through protection afforded by root excretions acting on the alkalinity of the soil?

At the end of the season the green weight of the plants was very much less on the limed than on the unlimed soils; the weight on the limed humus exceeded that on the limed sand by only a comparatively narrow margin. The weights per plant are given in Table 5.

TABLE 5. *Green weight per plant on heavily limed soils*

Species	Soil		
	Green weight per plant—grams		
	Sand	Sand with humus	Humus
Jack pine	.129	.132	.158
Pitch pine	.230	....	.252
Red pine	.209	.188	....
White cedar	.04	.03	.02*

* Younger than on other soils.

Although all the trees except cedar suffered severely, the Jack pine seemed to suffer a little less than the others. A certain number of Jack pines pulled through on all soils, though only 6 survived on the humus.

Curiously enough, wheat on alkaline soils suffered very little as compared with trees. On the limed sand and mixture of sand and humus the height

growth and weight were less than on the same soils without lime, but on humus there was very little difference between the limed and unlimed (see figure 5 and Tables 3 and 6). No matter how valuable experiments with herbs are in studying environmental relations of forest trees, toxicity and nutrition experiments in herbs must be applied to trees with caution. The green and dry weight per plant of the wheat, exclusive of roots, are given in Table 6.

TABLE 6. *Green and dry weight of wheat on heavily limed soils*

Soil	Green weight per plant, grams	Dry weight per plant, grams
Sand	.028	.008
Sand with humus	.054	.017
Humus	.344	.0786

Light Application of Burnt Lime.—It is not possible to give an absolute comparison of the influence of adding the small amount of burnt lime to the three soils studied, because the mild lime series was sown on June 23, 15 days after the others. Nevertheless some of the results are obviously due to differences in soil and are worth briefly considering.

The effect seems to have been intermediate between strong lime and absence of lime. On the coniferous trees, except cedar, the influence does not appear to have been beneficial, nor particularly injurious. Height growth throughout the season, always excepting cedar, was less than on the unlimed soils at the corresponding age, though this may be due partly to the late start as well as to the soil. Cedar found conditions more favorable on this series than on either of the others: in spite of the later start, height growth on both sand and on humus was nearly equal to that on unlimed soils by the end of the season (see fig. 2); there was also fair growth on the mixture of sand and humus, as compared with failure on this soil without lime.

Jack pine and pitch on the mixture of sand and humus passed the sand in height 3 to 5 days later than on unlimed soils. But red pine and cedar on the mixture did not catch up with that on the sand until the end of the season. By that time growth in height of all species on humus far surpassed that of the strongly limed humus, and, in spite of the later start, that on sand and on sand and humus equaled or surpassed that on the same soils with stronger lime.

Root growth was considerably less than on the unlimed series, probably partly on account of time of start and partly on account of soil, but showed greater length than on the more strongly limed series. Root area would undoubtedly have shown even greater superiority on the mild as against the strong lime.

In green weight there was not much difference between the lightly and heavily limed sandy soils, in spite of the late start of the former, but there

was a noticeable difference in health and vigor. On humus the green weight of the lightly much surpassed that of the heavily limed plants; the smaller application of calcium did not mask the benefits of the humus. Table 7 gives the green weight per plant on the lightly limed soils.

Table 7. *Green weight on lightly limed soils*

Species	Soil		
	Green weight per plant—grams		
	Sand	Sand with humus	Humus
Jack pine	.097	.111	.675
Pitch pine	.184	.206	.807
Red pine	.160	.159	.401
White cedar	.023	.015	.040

The growth of wheat was remarkably stimulated by the small amount of lime added, and far surpassed that on the other soils both in height and in green weight (see fig. 6 on the extreme right). Table 8 gives the green and dry weight per plant of wheat, exclusive of roots, on this series.

Table 8. *Green and dry weight of wheat on lightly limed soils*

Soil	Green weight per plant, grams	Dry weight per plant, grams
Sand	.060	.017
Sand with humus	.777	.080
Humus	1.99	.219

Summary

The growth of certain coniferous trees, of a broadleaf tree, and of wheat, on soils of varying humus content, and on similar soils rendered alkaline by the addition of air-slaked burnt lime, was determined.

To eliminate the influence of humus on moisture-holding capacity, all soils were watered.

Growth in height, root growth, and green weight were very much greater on pure humus than on pure sand, and were intermediate on the mixture of sand with 4 percent humus by weight, though nearer that on the sand. Height growth on humus continued till the middle of September; on sand it fell off early in July, and on the mixture of sand and humus it diminished by the middle of July.

The favorable influence of humus is attributed to its nitrogen content. The value of humus as a nutrient and its influence on the rate of growth in certain forests, independently of its influence on moisture, appears to be amply demonstrated.

Jack pine and pitch pine respond more to humus than do red pine or cedar. There is a possible indication that trees growing naturally on sterile soils are more strongly influenced by humus than those requiring better soils with other available nutrients than humus.

Cedar showed the beneficial effects of humus much less than the other species.

Wheat responded markedly to the humus, but less so than the coniferous trees except cedar. On the humus it showed the influence of the high nitrogen-low carbohydrate ratio.

Alkalinity produced by heavy applications of burnt lime was extremely unfavorable to all the trees except cedar. Sugar maple transplants died within 5 days, except for two on limed sand. A large proportion of the seedlings of the other species died, and those which survived made poor growth. Cedar came up on all three of the strongly limed soils, instead of on only the sand and humus as in the unlimed series, and grew slowly. The conifer roots on alkaline soils were brown and shriveled.

Alkalinity is more unfavorable to trees than acidity of the same departure from the neutral point. Cedar and other trees of lime soils may be an exception.

The toxicity of the burnt lime appeared to diminish somewhat after about 40 days' exposure, but still remained strong enough to be very unfavorable.

Wheat grew practically as well on the heavily limed as on the unlimed humus, showing the necessity for caution in applying to trees the results of nutrition studies in herbs.

In the lightly limed series growth in height, root growth, and green weight on the sand and mixture of sand and humus equaled or surpassed that on the stronger lime in spite of 15 days' later start. On the humus of this series all species excelled those on the more heavily limed humus in all respects and to a marked extent. Cedar did better on this series than on either of the others.

Wheat grew remarkably well on the light lime series, far surpassing that on the other soils.

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